

THE PERFORMANCE OF LIGHTWEIGHT CONCRETE BRICK CONTAINING
EXPANDED POLYSTYRENE AND PALM OIL FUEL ASH

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DEDICATION

*In the name of Allah the Most Beneficent, the Most Merciful.
All the praises and thanks be to Allah, the Lord of the 'Alamin.*

Special dedicated to:

My beloved mother, Halimah Binti Saidin,

My forever No.1 man, Mohd Yassin Bin Mohd Shariff,

My soulmate, Mohd Al-akhbar Bin Mohd Noor,

My super supportive siblings,

My sweet nephews and nieces,

Last but not least my loving in-laws.

Thank you so much for the unconditional love, trust and endless support.



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ABSTRACT

The development of lightweight building materials has contributed to the construction industry, probably because of its advantages in terms of lower weight and low construction cost. One of the most demanded lightweight building material is lightweight concrete brick. Owing to rapid population growth, the Malaysian government is paying close attention to housing development, particularly in urban areas which consequently increase the bricks demand. Apart from the strong demand for bricks, the government is also concerned about the development of sustainable building materials. One of the most preferable lightweight material used in the production of lightweight concrete brick is Expanded Polystyrene (EPS). However concrete materials containing EPS were observed to be low in strength and fire resistance performance. On the other hand, Palm Oil Fuel Ash (POFA) which is unprofitable agricultural waste that is extensively generated by the palm oil mill has been categorised as one of the pozzolanic materials that could be used as a cement replacement. Additionally, it is found that the optimum amount of POFA replacement could enhance the strength and also fire resistance performance of a concrete materials. Therefore, in the present study a new combination of replacement materials which is EPS and POFA as sand and cement replacement in the production of lightweight concrete brick is proposed. In this study there are 30 different types of concrete bricks made up of 0%, 20%, 30%, 40%, 50% of EPS replacement and 0%, 5%, 10%, 15%, 20% 25% of POFA replacement. The parameters measured for each types of brick include hardened brick density, compressive strength, water absorption, initial rate of absorption and fire resistance. On the basis of the findings, it is found that this new development of brick has certain advantages that are lighter in mass, high in strength and good fire protection in addition to being environmentally friendly. To summarise, brick sample consist of 40% of EPS and 20% of POFA (E40P20) has been classified as the optimum brick design.

ABSTRAK

Penghasilan bahan binaan ringan telah memberi sumbangan kepada industri pembinaan kerana ia memiliki kelebihan dari segi jisim yang lebih ringan dan kos pembinaan yang rendah. Salah satu bahan binaan ringan yang mempunyai permintaan yang tinggi adalah bata konkrit ringan. Oleh kerana peningkatan populasi yang pesat, kerajaan Malaysia memberi tumpuan terhadap pembangunan perumahan, terutama di kawasan bandar yang mengakibatkan peningkatan permintaan produksi batu bata. Selain permintaan yang tinggi terhadap batu bata, kerajaan juga prihatin terhadap pembangunan bahan binaan yang lestari. Salah satu bahan gantikan ringan yang paling popular dalam penghasilan bata konkrit ringan adalah *Expanded Polystyrene (EPS)*. Walau bagaimanapun, didapati bahan konkrit yang mengandungi *EPS* mempunyai kekuatan dan daya tahan api yang lebih rendah. Sebaliknya, *Palm Oil Fuel Ash (POFA)* merupakan sisa pertanian yang tidak menguntungkan banyak dihasilkan oleh kilang kelapa sawit telah dikategorikan sebagai salah satu bahan *pozzolanic* yang dapat digunakan sebagai pengganti simen. Selain itu, didapati bahawa jumlah penggantian *POFA* yang optimum dapat meningkatkan kekuatan dan juga prestasi daya tahan api bahan konkrit. Oleh itu, dalam kajian ini kombinasi baru dua bahan gantikan iaitu *EPS* dan *POFA* sebagai pengganti pasir dan simen dalam pembuatan bata konkrit ringan telah diperkenalkan. Dalam kajian ini terdapat 30 jenis bata konkrit yang terdiri daripada 0%, 20%, 30%, 40%, 50% penggantian *EPS* dan 0%, 5%, 10%, 15%, 20% 25% penggantian *POFA*. Parameter yang diukur untuk setiap jenis bata merangkumi ketumpatan bata, kekuatan, penyerapan air, kadar penyerapan awal dan ketahanan api. Berdasarkan penemuan tersebut, didapati bahawa penghasilan bata konkrit baru ini mempunyai kelebihan iaitu mempunyai jisim yang lebih ringan, kekuatan yang tinggi dan daya tahan api yang baik selain ia juga mesra alam. Sebagai kesimpulan, sampel bata konkrit yang terdiri daripada 40% *EPS* dan 20% *POFA* (E40P20) telah diklasifikasikan sebagai reka bentuk bata yang optimum.

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LIST OF SYMBOLS AND ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
Al_2O_3	-	Aluminium Oxide
BS	-	British Standard
BS EN	-	British adoption of a European standard
CaO	-	Calcium Oxide
CO_2	-	Carbon dioxide
C-S-H	-	Calcium silicate hydrate
CFC	-	Chlorofluorocarbon
d	-	Diameter
EPS	-	Expanded Polystyrene
FA	-	Fly Ash
Fe_2O_3	-	Ferric Oxide
GHG	-	Greenhouse gases
HCFC	-	Hydrochlorofluorocarbon
IRA	-	Initial rate of absorption
K_2O	-	Potassium Oxide
kg/m^3	-	kilogram per cubic meter
LOI	-	Loss On Ignition
$\text{min}/^\circ\text{C}$	-	Minutes per degree celsius
MgO	-	Magnesium Oxide
MPa	-	Megapascal

Na ₂ O	-	Sodium Oxide
OPC	-	Ordinary Portland Cement
POFA	-	Palm Oil Fuel Ash
PSA	-	Paper sludge ash (PSA)
R ²	-	R squared value
RHA	-	Rice Husk Ash
SF	-	Silica Fume
SIRIM	-	Standard and Industrial Research Institute of Malaysia
SiO ₂	-	Silicon Dioxide
SO ₃	-	Sulfur Trioxide
TIA	-	Timber Industrial Ash
UNEP	-	United Nation Environment Programme
UTHM	-	Universiti Tun Hussein Onn Malaysia
XRF	-	X-Ray Fluorescence
µm	-	Micrometer
%	-	Percentage



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CHAPTER 1

INTRODUCTION

1.1 Background of study

In Malaysia, the implementation of the sustainable construction and green building becomes the main attention of the construction industries as it has been introduced in the Construction Industry Transformation Programme (2016 – 2020). This programme has highlighted the transformation of construction industry in Malaysia into environmental sustainable as stated in the second thrust where the aims is transforming Malaysia into a country with low carbon emission, efficient waste management, environmentally protected and high quality of living standards.

Studies show that construction industries have contributed to the largest usage of natural resources and energy consumption that become the main issues of sustainability, not only in Malaysia but also all over the world (Kamar & Hamid, 2011; Kibwami & Tutesigensi, 2016). For instance, natural resources such as limes have been widely used in the production of cement. Cement is the major construction material that is used in the production of concrete and mortar in the construction industries. Hence, due to this matter, large usage of cement not only diminishes the natural resources but also contributes to the high emission of carbon dioxide (CO₂) and other greenhouse gasses (GHGs) (Rehan & Nehdi, 2005). Based on research and scientific reports, it has been proven that one of the main factors of global warming is due to the high concentration of carbon emission in the atmosphere (Kibwami & Tutesigensi, 2016; Zhang *et al.*, 2017). Referring to the United Nation Environment Programme, UNEP (2009) one-third of carbon emission was contributed by the building sector annually. Besides, vast consumption of other natural resources such as natural aggregates in the production of concrete should also be taken into consideration

because natural aggregates are non-renewable resources which are classified as the limited natural resources. According to Shuying *et al.* (2014), the consumption of the natural aggregates, sand and gravel for concrete industries have approximately reached 5 billion tons every year.

With regard to economy, Malaysia as a developing country is facing a high demand of housing due to the rapid growth of population. According to the Department of Statistic Malaysia Official Portal, Malaysia's population is projected to increase from 28.6 million in 2010 to 41.5 million in year 2040. This clearly shows that the rapid growth of Malaysia's population indirectly increases the housing demand especially in urban area. However, high prices of housing become the main problem to the society. Due to this matter, the government of Malaysia is focusing on low and medium cost housing project. As stated in the Eleventh Malaysia Plan (2016-2020), in the third strategic thrust which is enhancing exclusiveness towards an equitable society, the government is going to uplift B40 households (bottom 40% of households) towards middle-class society by increasing the provision of affordable housing.

Low cost housing could be implemented by minimising the consumption of raw materials and reducing the cost of transportation and handling process. Due to this, lightweight construction materials could help in reducing the cost of the construction. This is because lightweight building materials contain fewer raw materials and could reduce the cost of transportation and handling process. However, lightweight building materials have low strength compared to the heavy building materials. Hence, researchers have conducted a large numbers of studies in order to produce a lightweight building material with high strength.

However, researchers are confronted with big challenges in producing a high strength of lightweight building that comply the sustainable value (Ling & Teo, 2011). For each lightweight structure, there are three vital factors that should be taken into consideration in order to improvise the existing materials. The factors mentioned are in terms of technical, environmental and economic. The application of lightweight building materials significantly reduces the dead load of structures. Hence, by reducing the dead load it not only lessen the cost of the construction, but also the risk of earthquake damage as the earthquake acceleration and its magnitude is significantly affected by the weight of structure (Sayadi *et al.*, 2016).

Researchers have investigated many types of waste materials that have a good potential as a replacement material which could be used in the production of

lightweight structure. For instance, Sadrmomtazi *et al.* (2012) examined the mechanical features of lightweight concrete produced by using Expanded Polystyrene (EPS) as aggregates replacement and silica fume as cement replacement. From their findings, the combination of these waste materials showed a positive impact in the production of lightweight concrete with a high strength performance. Another study conducted by Ling & Teo (2011) also shows that the replacement of cement by Rice Husk Ash (RHA) have improvised the strength performance of lightweight brick.

Therefore, in the present study, an effort has been taken to develop another type of lightweight structure specifically a lightweight concrete brick where it has a combination of different kind of waste materials which is Expanded Polystyrene (EPS) beads as the partial replacement of fine aggregates and Palm Oil Fuel Ash (POFA) as the partial replacement of cement. The physical, strength and durability properties of brick have been identified by the laboratory test. Besides, some of the designated bricks have been selected and tested on its fire performance. Hence, this lightweight concrete brick is anticipated as a potential product for construction industries which has great advantages to the user in term of technical, environmental and economy.

1.2 Problem statement

Nowadays construction industry becomes one of the major factors that contribute to the sustainability problem all over the world (Brizga *et al.*, 2013). This is due to the high usage of natural resources such as lime for cement production and natural aggregates as the aggregates in the production of concrete. High demand for concrete in building and road construction triggers a high emission of carbon dioxide (CO₂) and greenhouse gases (GHGs) to the environment which causes global warming (Rahman *et al.*, 2014). According to Zhang (2013), the production of cement has caused high consumption of energy where 1 kg of cement consumes approximately of 1.5 kWh of energy in which about 1 kg of CO₂ was released to the atmosphere. Meanwhile, vast consumption of sand and natural aggregates in the construction industries has affected the geological structures of the earth. For instance, the digging process of the river sand has changed the bed shape position of the river which caused soil erosion (Shuying, 2014).

Furthermore, in the construction industry, heavy materials structure contributes to the high cost of production, transportation and handling process. In addition, heavy

materials structure is more vulnerable to the earthquake (Veyseh & Yousefie, 2003). Hence, development of lightweight structure is an alternative way to improvise the weaknesses of heavy material structures. For example, lightweight building materials could reduce the dead load of a building structure hence produce smaller structure elements i.e column, beam and foundation. By having smaller structure elements, therefore it reduces the construction cost. Many studies on lightweight building structures has been conducted. One of it is lightweight concrete brick or also known as lightweight sand brick (Ling & Teo, 2011). In this study, lightweight brick was produced by replacement of sand with the lightweight material which is Expanded Polystyrene (EPS) beads. It is found that, the replacement of EPS had significantly contributed to the reduction of the brick density.

Until now, brick is one of the important materials used in the building construction especially for houses. Having lightweight bricks in construction would give vast positive impact towards the industries. Besides reducing the dead load, it could reduce the total cost of construction. Large number of research has been conducted in the production of lightweight concrete bricks. One of the most favourable lightweight material used in the production of lightweight brick is EPS (Hernández-Zaragoza *et al.*, 2013; Ling & Teo, 2011; Xu *et al.*, 2012; Veyseh & Yousefi, 2003). Unfortunately, after lots of research have been conducted on lightweight brick containing EPS, several undesirable outcomes were revealed. For example, several studies conducted by Xu *et al.* (2012) and Veyseh & Yousefie (2003) stated that, the brick with EPS as the replacement material offered lower strength as compared to the normal concrete. Additionally, the replacement of EPS in the lightweight structure also found to be undermined the fire resistance properties. A study conducted by Sayadi *et al.* (2016) on lightweight concrete with EPS as replacement material shows that, higher percentage of EPS generated lower fire resistance towards specimen tested. This is due to the EPS particles shrank and lost their strength when subjected to higher temperature.

On the other hand, large number of researches on pozzolanic materials such as fly ash, silica fume, volcanic ash and coal bottom ash have also been conducted and studied. Researchers have found that these pozzolanic materials were used as the supplementary cementitious materials and these materials have improvised the strength performance of lightweight concrete. In Malaysia, one of the most well-known pozzolanic material used in the production of concrete is Palm Oil Fuel Ash

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